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DAY VS. NIGHT SAMPLING FOR SPIDERS IN GRAPE VINEYARDS

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ABSTRACT. We compared day sampling (between 0700 and 1100) and night sampling (between 1900 and 2300) of spiders on grapevines in a California vineyard in 1993 and 1994, shaking spiders from the vines onto a drop cloth and vacuuming them up. Pooled density of the seven most abundant spider species did not differ significantly between day and night sampling, nor did density of *Cheiracanthium inclusum* (Miturgidae), *Trachelas pacificus* (Corrinidae), *Oxyopes* spp. (Oxyopidae) or *Neoscona oaxacensis* (Araneidae). Under day sampling *Metaphidippus vitis* (Salticidae) was 60% more abundant and *Hololena nedra* (Agelenidae) more than 2.5 fold more abundant than under night sampling. Daytime sampling generally resulted in a higher percentage of capture for each spider taxa analyzed, but neither of the diversity indices (Shannon-Wiener, Simpson or Bray-Curtis) showed any difference between day and night sampling. Parameters generated by Taylor's power law indicate a uniform distribution for most spider taxa, which was not affected by sampling time with the exception of *H. nedra*. We suggest that at vineyard sites in California with a similar spider community, sampling can be limited to daylight hours if a sampling method is used which is sufficiently vigorous to dislodge spiders from their resting places.

Keywords: Sampling, night, vineyards, grapes

It is well recognized that many spiders exhibit diel activity patterns (Williams 1962), and therefore, the time of day at which sampling for spiders takes place has been considered by many researchers (e.g., Howell & Pienkowski 1971; Le Sar & Unzicker 1978; Nyffeler et al. 1987; Green 1999). Many species of the "wandering spider" families (e.g., Clubionidae, Miturgidae, Corrinidae) are nocturnal or exhibit periods of nocturnal activity (Marc 1990), which is true for many other spider families as well (e.g., most Araneidae and many Lycosidae) (Foelix 1982). Some families, such as the Salticidae, are almost exclusively diurnal. Others are active during the day as well as night (e.g., Oxyopidae).

Should researchers or pest management practitioners sample at night to obtain accurate estimates of spider density or diversity on vegetation in a given ecosystem? In recent studies, sampling time of day made little difference in spider density, but did affect diversity (Coddington et al. 1996; Dobyns 1997; Green 1999; Sorensen et al. 2002). However, sampling method will almost certainly play a role in determining the need to sample at night. For example, visual inspection that is undertaken exclusively in the day will likely miss the nocturnal spiders which rest in cryptic locations, and therefore a host of researchers using this method have included night as well as day sampling (e.g. Nyffeler et al. 1987). Howell & Pienkowski (1971) found that sweep netting, which primarily collects specimens from the distal end of shoots, favored diurnal hunters such as Salticidae and Thomisidae, when used during the day to sample spiders from alfalfa.

If the sampling method is efficient at collecting active spiders as well as extracting spiders from their resting places, then sampling might be done exclusively in the day, as diurnally active spiders will be easily caught and nocturnal spiders will be dislodged from their resting places. Vacuum sampling methods may achieve this, depending on the suction power and whether the spiders rest on relatively exposed locations on the plant. Using a D-vac, Le Sar and Unzicker (1978)

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found significant temporal variation in the vertical distribution of Tetragnathidae, Clubionidae, Thomisidae and Salticidae on soybeans and Green (1999) found that spider diversity in citrus orchards differed significantly when a D-vac sampling took place in the day compared to the night. These findings suggest that some spiders rested off of the vegetation sampled or that the D-vac suction was not sufficient to dislodge resting spiders from their resting places on the plants.

Beat or shake samples are designed to dislodge arthropods from vegetation; therefore, assuming that spiders are resting on the vegetation, all spiders, whether active or resting, should be sampled equally. McCaffrey et al. (1984), using the limb beat method on apples, found no differences in day vs. night sampling for Thomisidae, Dictynidae or Theridiidae and mixed results for Clubionidae and Salticidae. Unfortunately, their data set relied on just two sampling dates. In a southern hardwood forest using a foliage beating method, Coddington et al. (1996) found no difference in spider density between diurnal and nocturnal sampling. At the same study site Dobyns (1997) found no time of day difference using an intensive sampling strategy (a two-hour sampling effort applied three times per 24-hour period), but found slightly more spiders during the day than night using a less intensive strategy (the two-hour sampling just once per 24-hour period).

Another sampling method which might be effectively used to sample diurnal and nocturnal spiders without the need for round the clock sampling is the use of time-sorting pitfall traps (Alderweireldt 1994), but this method has limitations, as pitfall traps are not a very good estimator of density, and would be more useful for ground dwelling rather than arboreal spiders.

Spiders are the dominant predators on cultivated grapes in California's San Joaquin Valley (Costello & Daane 1999). Two studies have been published which compared sampling methods to estimate spider density on the vines (Costello & Daane 1997; Roltsch et al. 1998), but there have been no comparisons made of day sampling vs. night sampling to determine their effects on estimates of density or diversity. The intent of this study was to compare day vs. night sampling using a single sampling method, the drop cloth, to determine if night sampling is important for estimating spider density or diversity in the grape agroecosystem. We focused on seven spider species which dominated our study site. Of these, *Metaphidippus vitis* (Cockerell 1895) (Salticidae) is diurnal; *Trachelas pacificus* (Chamberlin & Ivie 1935) (Corinnidae), *Cheiracanthium inclusum* (Hentz 1847) (Miturgidae) and *Neoscona oaxacensis* (Keyserling 1864) (Araneidae) are considered nocturnal; and *Hololena nedra* Chamberlin & Ivie 1942 (Agelenidae), *Oxyopes scalaris* Hentz 1845 and *Oxyopes salticus* Hentz 1845 (Oxyopidae) are considered active both day and night.

METHODS

Study site and sampling methods.—Day vs. night sampling comparisons were part of a larger study of spider densities on grapevines with and without ground cover (Costello & Daane 1998). The study site was a table grape vineyard (cv. Ruby Seedless) near Reedley, Fresno County, California. The experimental design was a randomized complete block, with two treatments (ground cover present during the grape growing season vs. clean cultivation) and five replicates of each block. Each treatment plot was 1.4 ha (8 rows wide by 80 vines long). Ground cover had no effect on spider density on the vines overall, and little effect on individual spider species density (Costello & Daane 1998). Because there was no ground cover × sampling time interaction ($P > 0.05$), the data were analyzed for sampling time without regard to ground cover treatment. To test the hypothesis that sampling time of day made a significant difference in the estimate of population density, we took two daytime samples (0700–1100 hours) and two nighttime samples (2000–2400 hours) from each plot (i.e., across ground cover treatments) monthly from May–September in 1993 and 1994 (total of 40 samples). We sampled spiders from the vines as a two-person team and used the drop cloth method, which involved laying a 9 x 3 m muslin sheet on the ground underneath the area covered by the trunk, canes, and foliage of two adjacent vines. For ~30 sec. we shook the foliage and beat the vine trunks with mallets to dislodge spiders onto the muslin sheet, and collected the spiders with battery-powered vacuums. To sample at night, we used battery powered headlamps.

In the study vineyard, the vines were trained to a bilateral cordon, and trellised on a 0.9 m crossarm with 2 catch wires. Rows were spaced 3.6 m wide and vines were spaced 2.4 m within the row. Pesticides used during the 2 year period included the fungicides sulfur, copper and myclobutanil for control of grape powdery mildew, *Uncinula necata* Burrill, and the insecticide sodium fluroaluminate for control of lepidopteran pests.

Statistical analysis.—We analyzed the density of the seven most abundant spider species, grouped into six taxa, each of which comprised at least 3% of the total number of spiders collected. These were *T. pacificus*, *C. inclusum*, *M. vitis*, *H. nedra*, *N. oaxacensis*, and *Oxyopes* spp. *Oxyopes scalaris* and *O. salticus* are grouped together as *Oxyopes* spp. for purposes of the analysis because they cannot be easily distinguished as immatures. In addition, we analyzed the pooled abundance of these seven species. We log transformed the data and analyzed them by repeated measures ANOVA (SAS Institute 2000), using date as the repeated measures variable. Because there was no interaction between sampling time and year for spider density nor diversity ($P > 0.05$), the two year period was analyzed as a complete data set, and sampling dates are presented as the mean julian date of the two sampling years.

Spider species diversity in day vs. night sampling was estimated in several ways. A similarity index was created using the Bray-Curtis measure (Bray & Curtis 1957; Krebs 1989):

$$B = \frac{\sum |X_{ij} - X_{ik}|}{\sum (X_{ij} + X_{ik})}$$

where B = the Bray-Curtis measure of dissimilarity and X_{ij}, X_{ik} = percentage of species i in each sample j (day sample) or sample k (night sample). We have chosen to use this index as a measure of similarity by using the complement of B (i.e., 1—B), as suggested by Wolda (1981). Values of the index range from 0 (completely dissimilar) to 1.0 (completely similar). The Shannon-Wiener index (Southwood 1978), which is sensitive to rare species, was calculated as:

$$H = -\sum p_i \log p_i$$

where p_i is the proportion of the total number of species or genera identified. The Simpson index (Southwood 1978), which is more sensitive to common species, was calculated as:

$$D = 1/\sum p_i^2$$

where p_i, again, is the proportion of the total number of species or genera identified.

To determine the effect of sampling time on spider dispersion, the mean and variance of spider abundance for each sample date (natural log) were used to generate dispersion parameters using Taylor's power law (Taylor 1961):

$$s^2 = a\mu^b$$

where s^2 is the variance, a is a sampling parameter, μ is the mean, and b is an aggregation parameter. The aggregation parameter (b) describes species dispersion: Values of $b > 1$ indicate a clumped distribution, of $b = 1$ a random distribution, and of $b < 1$ a uniform distribution (Taylor 1961).

RESULTS

The spider community on grapes in this vineyard consisted of at least 15 families, comprising 22 identified species, with seven species making up 95% of the community. Over the two year period, a total of 6,410 spiders was collected: 3668 during the day, and 2742 during the night (Table 1). Spider density per vine (the seven most abundant species pooled) did not differ significantly between day and night (Table 2). In addition to the overall counts, the absolute number of spiders collected was higher for every spider taxon during the day (Table 1), but there was no significant difference in spider density with day vs. night sampling of the spiders *C. inclusum*, *T. pacificus*, *Oxyopes* spp. or *N. oaxacensis* (Fig. 1, Table 2). However, for two species there were significant differences ($P < 0.01$) between treatments: *M. vitis* was 60% more abundant under day sampling, and *H. nedra* was more abundant under day sampling by more than 2.5 fold (Fig. 1, Table 2).

For each spider taxon a higher percentage overall was collected in the day than during the night (Table 1). However, this did not have a significant impact on the diversity indices. There was a trend toward higher overall spider diversity early in the season, but there were no significant differences in diversity for ei-

Table 1.—Total number of spiders collected and percentage of spiders collected by sampling time and spider taxon, 1993 and 1994 seasons combined.

Spider taxon	Total number of spiders collected		Percentage of all spiders collected	
	Day	Night	Day	Night
Trachelas pacificus	1424	1214	22.2	18.9
Cheiracanthium inclusum	690	576	10.8	9.0
Oxyopes spp.	630	373	9.8	5.8
Metaphidippus vitis	402	244	6.3	3.8
Neoscona oaxacensis	165	123	2.6	1.9
Hololena nedra	174	63	2.7	1.0
Theridion spp.	63	41	1.0	0.6
Linyphiidae	49	38	0.8	0.6
Salticidae	27	13	0.4	0.2
Thomisidae	19	10	0.3	0.2
Lycosidae	8	19	0.1	0.3
Gnaphosidae	9	16	0.1	0.2
Anyphaenidae	6	9	0.1	0.1
Total spiders	3668	2742	57.22	42.77

ther the Shannon-Wiener index ($P = 0.98$) or the Simpson index ($P = 0.73$) between day and night sampling (Table 3). In addition, the Bray-Curtis similarity index was 0.89, which is considered quite high. No spider taxon was found exclusively during either sampling period.

The spider seasonal abundance pattern (i.e., spider density over time) was not significantly altered by time of day sampling for any spider species except *T. pacificus* (sampling by date interaction: $F = 9.56$, $df = 4, 124$, $P < 0.001$). For this spider, night sampling showed a small early season peak and larger late season peak in density, but only one late season peak for day sampling (Fig. 1). Day and night sampling densities peaked earliest for *N. oaxacensis* and peaked on the last sampling date for *C. inclusum*, *H. nedra* and *Oxyopes spp*. Peak density for *M. vitis* was mid to late season for both day and night sampling (Fig. 1).

Regressions of s^2 against μ were significantly different from zero for every spider taxon and sampling time ($P < 0.002$, Table 4). With one exception, values of b were <1, indicating a uniform distribution for all spiders, which was not changed by sampling time. The one exception was night sampling of *H. nedra*, which produced a value of 1.17 for b, indicating a random distribution.

DISCUSSION

Although the sum total of spiders (all spider taxa combined) was higher under day sampling, we found no overall statistically significant difference in spider density nor diversity

Table 2.—Mean spiders per vine and summary statistics from the analysis of variance, 1993 and 1994 seasons combined.

	Mean spiders per vine		ANOVA		
	Day	Night	*F*	*df*	*P*
T. pacificus	6.47 ± 0.77	5.67 ± 0.44	0.40	1, 31	0.533
C. inclusum	3.13 ± 0.54	2.69 ± 0.44	0.07	1, 31	0.794
Oxyopes spp.	2.86 ± 0.65	1.74 ± 0.34	0.92	1, 31	0.344
M. vitis	1.82 ± 0.18	1.14 ± 0.11	9.36	1, 31	0.004
N. oaxacensis	0.75 ± 0.11	0.54 ± 0.06	2.03	1, 33	0.163
H. nedra	0.79 ± 0.10	0.29 ± 0.04	8.97	1, 31	0.005
Total spiders	15.84 ± 1.86	12.09 ± 1.01	0.67	1, 34	0.420

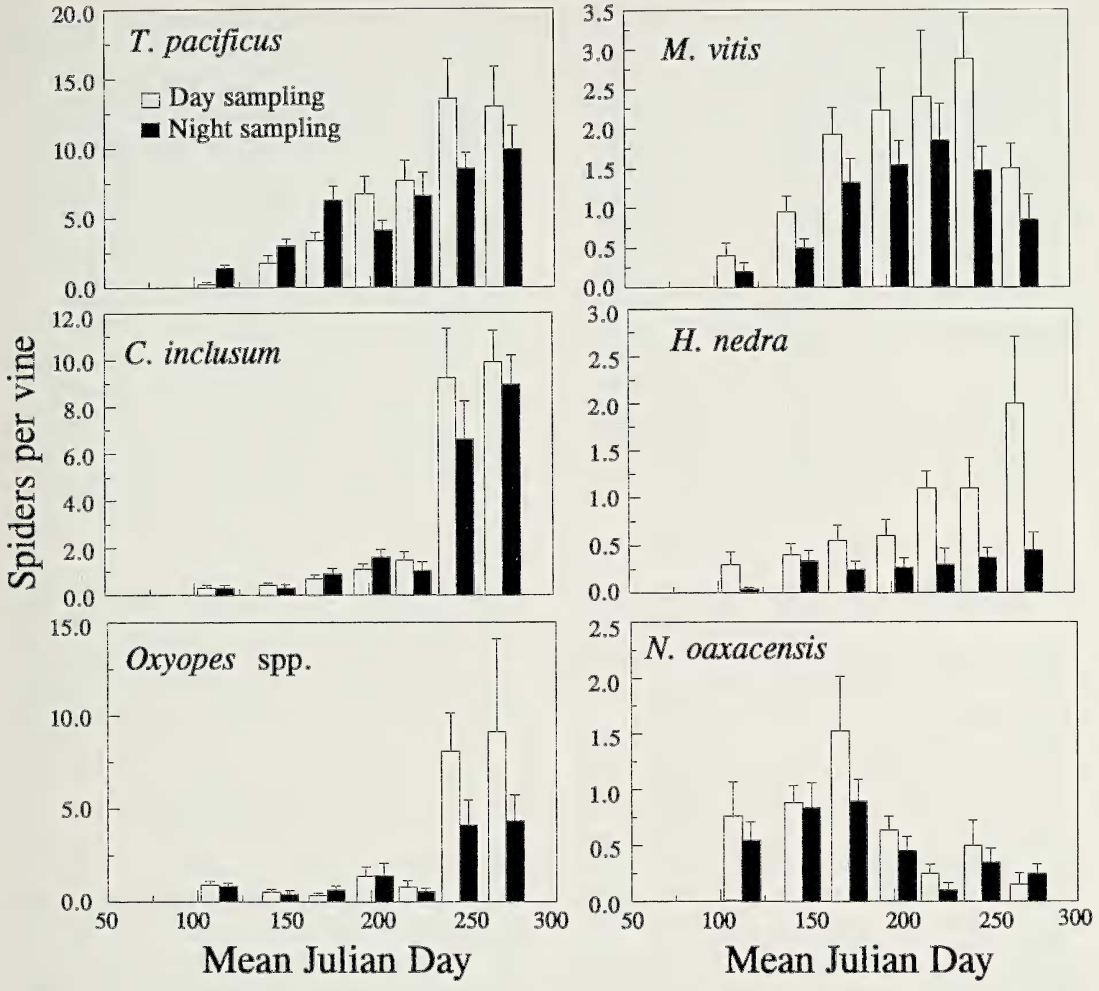

Figure 1.—Spider density per vine of the six most common taxa, 1993 and 1994 data combined, with the julian dates of the two study years averaged. Open bars represent day sampling, and closed bars night sampling. *Metaphidippus vitis* and *H. nedra* showed significantly higher density with day sampling ($P < 0.01$). No significant differences were found in spider density for any of the other taxa.

Table 3.—Shannon-Wiener (H) and Simpson (D) diversity indices, 1993 and 1994 data combined, with corresponding *P*-values.

Mean Julian Day	H		D	
	Day	Night	Day	Night
112	0.83	0.76	5.88	4.52
147	0.93	0.75	6.94	3.89
173	0.79	0.67	4.61	2.94
202	0.71	0.74	3.22	4.09
222	0.61	0.64	2.82	2.94
247	0.68	0.67	3.80	3.46
272	0.65	0.63	3.69	3.28
	$P = 0.98$		$P = 0.73$	

between diurnal and nocturnal sampling. Our findings are similar to other studies which used beating or shaking of vegetation as a sampling method (McCaffrey et al. 1984; Coddington et al. 1996; Dobyns 1997), in that few differences in overall spider density were found with day vs. night sampling. Dobyns (1997) found that spider density was significantly different (more spiders were found during the day) but only for a low intensity sampling method, and concluded that sampling method was more important than sampling time of day. Sorensen (2002) found an interaction between sampling time of day and sampling method, with some methods producing

Table 4.—Regression statistics of ln s^2 against ln μ for generation of Taylor's power law parameters.

Spider	Sampling time	a	b	R^2	P
T. pacificus	Day	0.472	0.502	0.834	0.0001
	Night	0.729	0.447	0.831	0.0001
C. inclusum	Day	0.256	0.720	0.987	0.0001
	Night	0.325	0.599	0.908	0.0001
Oxyopes spp.	Day	0.296	0.434	0.917	0.0001
	Night	0.359	0.399	0.923	0.0001
M. vitis	Day	0.481	0.440	0.666	0.0013
	Night	0.278	0.599	0.795	0.0001
H. nedra	Day	0.285	0.458	0.778	0.0002
	Night	0.056	1.165	0.743	0.0004
N. oaxacensis	Day	0.300	0.393	0.705	0.0007
	Night	0.160	0.743	0.866	0.0001
All spiders	Day	0.902	0.451	0.821	0.0001
	Night	1.131	0.427	0.825	0.001

higher abundance of spiders at night. Other studies have concluded that sampling method can lead to very different estimates of spider density and diversity (Costello & Daane 1997; Roltsch et al. 1998).

When analyzed by taxon, we found two species, *M. vitis* and *H. nedra*, significantly different in density with respect to time of day sampling, and both of these were more abundant with day sampling. *Metaphidippus vitis*, like most other salticids, is an active diurnal hunter that searches for prey out on the leaves and shoots and can quite easily be shaken off during the day. Could it be that *M. vitis*, and perhaps other salticids, rest during the night in relatively deep crevices, and are therefore more difficult to shake out? For *H. nedra*, finding a logical explanation is more difficult. This agelenid sits and waits for prey to land on the flat, sheet like portion of its funnel shaped web, and presumably, will respond to prey during the day or night. Because *H. nedra* does not leave its web to rest, the explanation for this difference cannot be that it is not as accessible during the night. However, it is possible that behaviorally, its response to disturbance at night is to retreat rather than to flee. We wonder if this might not be related to lower temperatures at night: *H. nedra* is a very quick and agile spider, and perhaps because lower temperatures do not allow it to flee as fast at night, it switches to a retreat response.

Given that the diurnally active hunting spider *M. vitis* was sampled at a higher density during the day, why did we not find parallel results with the nocturnal spiders *T. pacificus*, *C. inclusum* and *N. oaxacensis*? There are two possibilities, the first being that their resting places are on the foliage, rather than in recesses or crevices on the bark of the trunk, or in the leaf litter or soil underneath the vine. This possibility is most plausible for *C. inclusum* and *N. oaxacensis* than for *T. pacificus*. The silken bivouacs of *C. inclusum* are commonly encountered on the foliage of grapevines, and *N. oaxacensis* is well known for stringing its orb web between the rows of grapevines and resting on the foliage during the day. However, this explanation does not fit well with *T. pacificus*. Few bivouacs of this species have been observed on grape foliage, as this spider has a penchant for hiding under the bark of the trunk. This brings us to the second possibility, that *T. pacificus* is not as nocturnal as we thought, and may be just as active during the day as during the night.

Our results do not indicate that estimates of spider diversity are affected by time of day of sampling, in contrast to findings of other researchers. Green (1999) found that generic richness differed significantly with sampling time in over 40% of samples. Coddington et al. (1996) and Dobyns (1997) found some spider species and even entire families only at night, and Sorensen et al. (2002) found species unique to both day and night. The implication is that night sampling was necessary to achieve a more accurate estimate of species richness and a more complete picture of the

spider fauna. The reasons our results differed may have to do with the ecosystem studied: our grape agroecosystem was much lower in species richness than the southern hardwood forest (Coddington et al. 1996), subtropical citrus orchard (Green 1999) or afromontane (Sorensen et al. 2002) ecosystems.

We suggest that in California vineyards with similar spider communities, if a method is used which is sufficiently vigorous to dislodge spiders from their resting places, sampling can be limited to daylight hours. Although we found no difference in spider species diversity between day and night sampling, it is possible that at sites with higher species richness than ours, sampling time of day could influence estimates of diversity. As for species density, there was no under representation of nocturnal spiders, which is the main concern when limiting sampling to daylight hours; each of the two spider species (*M. vitis* and *H. nedra*) which differed between day and night sampling was more abundant with day sampling.

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